

Dye Yield, Color Strength and Dyeing Properties of Natural Dyes Extracted from Ethiopian Dye Plants

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Abstract

With the aim of scientific investigation on natural dye yielding plants of Ethiopia, few dye plants which are traditionally used for cotton dyeing in Ethiopia were selected. Crude dyes in powder form were isolated after evaporation of aqueous extracts. The color strength and color mass equivalences of the aqueous extracts compared to synthetic dye (commercial C I Reactive Red 4) were determined. Calculation of color equivalence gives an idea of the necessity of using large quantities of raw dye plant to get a particular depth of shade compared to synthetic dye. Cotton fabric was dyed without and with alum and iron (II) sulphate mordants. The dye uptake (K/S), CIE L*a*b*, wash and light fastness results indicated that dye plants traditionally used in Ethiopia for cotton dyeing have considerable potential for application as a source of natural dyes. Attempts were made to correlate crude dye yield and color strength of extracts. However, no relationship existed between these parameters. This is attributed to the absence of knowledge of exact coloring components and chemical structures of crude dye obtained after evaporation of dye extracts. The emphasis of the paper is on the color strength, color yield equivalence compared to commercial C I Reactive Red 4 and dyeing behavior without and with mordant. No attempt was made for dye chemical structure determination due to lack of purity of isolated dye from aqueous extracts. Use of aqueous extract without further purification is a common practice of dyeing with natural dyes.

Keywords

Dye Plant; Extraction; Dyeing; Mordant; Crude Dye Yield; Color Strength

Introduction

The interest in use of dyes and colors of natural plant sources for coloring textile, food, and pharmaceutical and cosmetics products is increasing in recent years. This increasing demand for plant origin of dyes particularly for textile application is due to consumer desire to replace synthetic chemicals by natural

compounds (Goodarzian and Ekrami, 2010). Skin demands safer textile products especially for babies and children as reported in the EU needs for qualified products (Anklaker et al., 1998, Angelini et al., 2003). . The usage and production of natural dyes from plant sources has become better known due to growing awareness of the environment and health care (Shahid, Shaukat Ali, and Ijaz, 2009).

Coloring components are derived from roots, barks, leaves, fruits and flowers of plant sources (Anjali, Deepali, 2012). However, the dye yield and pure dye content in dye plant is usually quite low compared to synthetic dyes (Mary Hancock, 1997). Hasan Baydar and Tahsin Karadogan reported that the three year old madder plants gave root yield about 4.8 tons per hectare with dye yield of 37.7 kg per hectare, only with pure dye content of 2.3-4.4% of the total weight of the dried root (Hasan and Tahsin, 2006). The tinctorial strength (weight needed to produce a color of required depth on fiber) also needs to be considered. About 1.5 g of a synthetic dye is required to dye 100 g of fiber in medium depth of shade, whereas; about 120-240 g of dry plant dye which may be equivalent to 500-1000 g of fresh dye plant source would be required to achieve the same result. The amount of fresh plant material needed to replace synthetic dye with natural dyes for dyeing the annual production of cotton and wool is estimated to be 191 million tons (Mary Hancock, 1997). These relationships have important implications for the production of dye crops when the replacement of synthetic dyes with natural dyes is taken into consideration.

The flora of Ethiopia is very diverse with an estimated number between 6,500 and 7,000 species of plants, of which about 15% are endemic. It has been said that Ethiopia is the fifth largest floral country in tropical

Africa. The country has a potential of 65% arable land with geographic diversity and only 15% is cultivated at present (Ethiopian Center, 2012). In spite of these rich plant resources, there is insignificant scientific study on identification of color yielding plants and coloration of textiles by dye plants. Until recent times, there has been natural dyeing tradition in some areas of the country particularly in Ethiopian Orthodox Church Monasteries in the North-West regions of the country.

The work in this paper is primarily focused on the determination of the amount of crude dye yield after evaporation of aqueous extracts of selected dye plant sources. Both color strength and theoretical color mass equivalences to commercial C I Reactive Red 4 were determined following the analogy of work reported by Thomas Bechtold, et al. (Thomas Bechtold, et al., 2006). Attempts were also made to correlate crude dye yield and color strength equivalence for any relationship between them. Wherever possible the results are interpreted with scientific support from the literature. No attempt was made for dye structure determination due to lack of purity of isolated dye from aqueous extracts.

Materials and Methods

Materials

TABLE 1 LOCAL AND SCIENTIFIC NAMES OF DYE PLANT SOURCES

Local name	Botanical name	Plant parts	Geographical Distribution
Bamiba	<i>Ficus sycamores</i>	Bark	Ethiopia, Kenya, Sudan, Egypt, Eritrea
Dokima	<i>Syzygium guineense</i>	Bark	Ethiopia and in many parts of Africa
Warica	<i>Ficus sycamores</i>	Bark	Ethiopia, Kenya, Sudan, Egypt
Inkoy	<i>Ximenia Americana</i>	Leaves	Native to tropics including Ethiopia
Wonbela	<i>Eriobotrya japonica</i>	Bark	Ethiopia, Egypt, Kenya, Sudan
Abalo	<i>Combretum collinum</i>	Leaves	Ethiopia, Southern Africa, Madagascar
Zana	<i>Stereospermum kunthianum</i>	Leaves	Ethiopia, Zambia, Democratic republic of Congo
Gesho	<i>Rhamnus prinoides</i>	Leaves	Occurs from Ethiopia to South Africa
Gimea	<i>Tagetes minuta</i>	Flower	Ethiopia, Eritrea, Djibouti, Kenya
Fesson	<i>Scadoxus multiflorus</i>	Flower	Ethiopia, Zimbabwe, South Africa

1) Fabric

A commercially prepared ready-to-dye plain weave 100 % cotton fabric of 140 g/m², 32 ends/ inch and 24 picks/ inch was purchased from Bahir Dar Textile Share Company, Ethiopia.

2) Dye Plants

Traditionally used 10 varieties of dye yielding plants were collected from north-west region (Daga Esthifanos Monastery), situated in Lake- Tana of Ethiopia. The local and botanical names of dye plants used in the text are given in Table 1.

3) Chemicals

Laboratory grade alum ($KAl(SO_4)_2 \cdot 12 H_2O$) and ferrous sulphate ($FeSO_4 \cdot 7 H_2O$) are used as mordants. Sodium sulphate (Na_2SO_4) has been used to facilitate dye bath exhaustion. Industrial soap was used for wash fastness test. The dye baths were maintained at pH 7 using sodium carbonate (Na_2CO_3).

Methods

1) Dye Extraction

The selected natural dye plant sources were dried by exposure to sunlight, conditioned and converted to powder form by using laboratory grinding machine. The dye extraction was carried out for 1 hour by boiling 21 grams of dye plant source in powder form, with 420 ml of distilled water in a beaker on a hot plate with temperature regulator. The mouth of the beaker was covered with aluminum foil to prevent the excessive loss of water during extraction. After the boiling period, the dye extract in hot condition was filtered through fine cotton fabric. The filtrate was cooled and further filtered through Whatman filter paper. Extraction was performed two times from the equal weight of dye material under identical conditions. The percentage weight of crude solid dye was determined after evaporation of the extracts in relation to the original weight of dye material used for extraction.

2) Crude Dye Yield

The extracted and filtered dye solutions were placed in the beaker and heated on a hot plate with temperature regulator at 70^o C to get solid dye by evaporation of water. Solid dye powder obtained after evaporation was conditioned for 24 hours at 20^o C, 65% relative humidity. Then it is weighed

and termed as crude solid dye or crude dye. The percentage yield of crude dye was calculated (using equation 1) in relation to the original weight of dye material used for extraction.

$$Wdy = \frac{W_{be} - W_{ae}}{W_{be}} \times 100 \quad (1)$$

Where Wdy = percentage yield of crude dye; W_{be} - dye material weight before extraction (g); W_{ae} - crude solid dye material weight after evaporation of extracts (g). All weighings were carried out on electronic digital balance (Mettler Toledo AE 200) with 0.0001 gram accuracy.

3) Color Strength Equivalence, (Ceq)

Color strength equivalence and mass equivalence for each dye plant compared to commercial reactive dye Cibacron Brilliant Red 3 B-A (C I Reactive Red 4) was determined using the approach suggested by Thomas Bechtold et al (Thomas Bechtold, et al., 2006).. The absorbance (A_{extr}) of aqueous extract of each dye plant source was measured at the wavelengths of maximum absorption (λ_{max}) using spectrophotometer (Dr Lange CADAS 200, Germany). Care was taken to keep the absorbance value within 2 by suitably diluting the known volume of dye extract. The absorbance (A_{extr}) for each dye plant solution was measured three times and the average results for each dye plant source are reported. The absorbance (A_{extr}) value for each dye plant source was multiplied with corresponding dilution factor (DF) during calculation of equivalent color strength compared to commercial reactive dye Cibacron Brilliant Red 3 B-A (C I Reactive Red 4), using equation 2.

$$Ceq = \frac{A_{extr}}{\epsilon_{RR4}d} \quad (2)$$

Where Ceq - color strength equivalence of Reactive Red 4 ($g\ dm^{-3}$); A_{extr} = absorbance of dye plant extracts; ϵ_{RR4} - extinction coefficient of commercial Reactive Red 4 ($9.7\ dm^3\ cm^{-1}\ g^{-1}$ at $\lambda=508nm$) and d - path length of cuvette (cm).

4) Dyeing Procedure

The extracted solution of each dye plant source was applied to cotton fabric with mordants and without mordant under identical conditions. Direct dyeing (without mordant) method was performed to find out whether the extracted dye showed affinity to cotton in the absence of mordant (Dominique, 2007,

Kulkarni, et al., 2011, Harish, et al., 2010, Ashis Kumar and Priti, 2009, Tsatsaroni, et al., 1995).

The pH of the aqueous extracts was acidic; therefore the extracts were neutralized to pH 7 before dyeing by careful addition of dilute sodium carbonate solution. Dyeing was carried out with 1:20 material to liquor ratio (M.L.R). The concentration of the dye material used was 70% of fabric weight (o.w.f.). The dyeing temperature was raised by $2.5^\circ C/min$ and dyeing was carried out at $80^\circ C$ for 1 hour in Mathis LABOMAT sample dyeing machine. After half of dyeing time 3 g/l sodium sulphate (Na_2SO_4) was added as exhausting agent. For mordant dyeing, the fabrics were mordanted prior to dyeing by treating with laboratory grade of potassium aluminum sulfate and ferrous-iron (II)-sulphate with liquor ratio of 1:40 at $100^\circ C$ for 45 minutes with concentration of 5% (o. w. f.) for both mordants. Mordanting was carried out in the same machine used for dyeing.

Results and Discussion

Dye Yield

During dyeing of textile material (cotton, wool or silk) with natural dyes; the concentration of dye source taken for dyeing is substantially high (up to 100% o.w.f) even more. This can be accounted to low dye yield from dye plant source and low color strength of the extracted dye solution compared to synthetic dyes. At this stage, it is essential to distinguish the dye yield and color strength equivalence (Ceq). Dye yield is the quantity of crude dye powder obtained after evaporation of water from the extracted dye solution. On the other hand, the color strength equivalence represents the color intensity of extracted dye solution compared to synthetic dye. In the present study, the color strength equivalence of aqueous extract of dye plant was compared with commercial C I Reactive Red 4. The reason for selecting C I Reactive Red 4 is the availability of its extinction coefficient value which is essential for the determination of color strength equivalence. In fact, any other synthetic dyes can be selected whose extinction coefficient value is known. The solid dye powder left after the evaporation of water from aqueous extracts was termed as crude dye yield as no attempt was made for further purification of dye powders. The results of crude dye yield are given in Table 2.

TABLE 2 CRUDE DYE YIELD FROM DYE PLANT SOURCES

Local name	Plant parts	Crude dye yield (%)
Bamiba	Bark	17.64
Dokima	Bark	23.87
Warica	Bark	26.33
Inkoy	Leaves	24.33
Wonbela	Bark	14.14
Abalo	Leaves	17.86
Zana	Leaves	17.09
Gesho	Leaves	24.48
Gimea	Flower	15.43
Fesson	Flower	20.76

The dye yield for 10 different dye plant sources varied from 14.14-26.33%. The lowest and highest dye yields are obtained from Wonbela (bark) and Warica (bark) respectively. There are considerable variations in the dye yield values of some dye plant sources reported in the literature, for example safflower (*carthamus tinctorial* L.) florets yield 25-36% of yellow colorants, but only 0.3-0.6% of red. Young Fustic, Venetian, Sumace or Wig Tree (*Rhus Continus* L.) branches and leaves contain different colors from an average of 18-20% up to 35% of dry weight of the material and the bark of Evergreen Buckthorn (*Rhamnus alternus* L.) contains an assortment of glycosides of hydroxyl anthraquinones as much as 20% of its dry weight (Hasan and Tahsin, 2006). The 19% dye yield was reported with ethanol-water (40:60) extraction method from pomegranate (*Punica granatum*) peel (Ester, 2004). It must be pointed out that in the present study no attempt was made to further purify the solid dye obtained from each dye plant source. Therefore, the dye yield values correspond to crude dye rather than purified dye. It is expected that the crude dye yield results of the present study would be reduced to lower values when further purified.

TABLE 3 COLOR STRENGTH EQUIVALENCE (CEQ) AND COLOR MASS EQUIVALENCE (MEQ) OF NATURAL DYE PLANT SOURCES COMPARED TO COMMERCIAL C I REACTIVE RED 4

Local name	Plant parts	Absorbance		Ceq, g dm ⁻³ (color strength)	Meq, g kg ⁻¹
		Aextr	DF*		
Bamiba	Bark	1.29	12	1.60	32.00
Dokima	Bark	1.59	10	1.56	31.29
Warica	Bark	1.64	8	1.35	27.00
Inkoy	Leaves	1.52	8	1.25	25.00
Wonbela	Bark	1.82	14	2.63	52.00
Abalo	Leaves	1.62	13	2.17	43.40
Zana	Leaves	1.76	12	2.18	43.60
Gesho	Leaves	1.73	14	2.50	23.60
Gimea	Flower	1.69	30	5.22	104.00
Fesson	Flower	1.36	11	1.54	30.80

Color Strength Equivalence

It is well known that in case of natural dyes the shade depths of dyed material are pale to medium in majority of cases with only few exceptions such as indigo and madder. This is obviously related to the dye yield and color strength of the dye extract. Thomas Bechtold, et al., determined the color strength equivalence (Ceq) compared to that of commercial reactive dye Cibacron Brilliant Red 3 B-A (C I Reactive Red 4) for the colors extracted from plant wastes released from the food and beverage industry (Thomas Bechtold, et al., 2006).

In the present study, the color strength equivalence (Ceq) and the color mass equivalence (Meq) of 1 kg dye plant material to commercial reactive dye Cibacron Brilliant Red 3 B-A (C I Reactive Red 4) was determined from the equation 2 as suggested by Bechtold. The dilution factor of absorbance (Aextr) was taken into consideration during the calculations of Ceq. The results are shown in Table 3.

Depending on the dye plant source used for extraction, the absorbance (Aextr) obtained ranged from 4.65-50.7, which corresponds to color strength equivalence Ceq of 1.25 g dm⁻³ to 5.22 g dm⁻³ (calculated as commercial Reactive Red- 4 synthetic dye).

The theoretical color mass equivalence (Meq) for 1kg of dye plant source and the commercial Reactive Red 4 was calculated indirectly based on equation 2 and the results are shown in column 6 of Table 3. The mass equivalent (Meq) values indicated that 1 kg of different dye plants yielded 23.6-104 g kg⁻¹ equivalent of commercial Reactive Red 4.

Thomas Bechtold et al. (Thomas Bechtold, et al., 2006), reported absorbance ranging from 0.3 to 28.1 for dyes extracted from colored plant wastes of the food and beverage industry. Based on this absorbance range, they reported color strength equivalence (Ceq) and color mass equivalence (Meq) of 0.62-2.9 g dm⁻³ and 0.62-57.9 g kg⁻¹ respectively to commercial C I Reactive Red 4. The absorbance (Aextr), color strength equivalence (Ceq) and color mass equivalence (Meq) values in this work are greater than the results reported by Thomas Bechtold et al. This indicates that dye plant sources which are traditionally used in Ethiopia for dyeing cotton material have considerable potential for application as a source of natural dyes.

Relationship Between Dye Yield and Color Strength Equivalence

In order to find out whether there is any relationship between dye yields and color strength equivalence of extracts of dye plant sources, the results of dye yield plotted against color strength equivalence (Ceq). The relationship is shown in Figure 1.

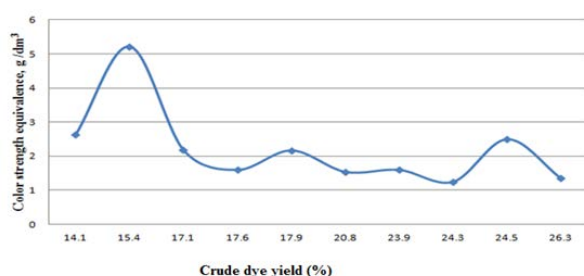


FIG. 1 RELATIONSHIP BETWEEN COLOR STRENGTH EQUIVALENCE AND DYE YIELD

The dye yield values for all dye plants are arranged in ascending order on x-axis and y-axis represent the color strength equivalence (Ceq) compared to commercial C I Reactive Red 4. With normal logic, it would have been anticipated that the plant source showing high dye yield will give high color strength. However this logic is not followed as represented in Figure 1. Careful examination revealed no pattern or definite relationship between color strength equivalence and crude dye yield. For example, Gimea (flower) having relatively lowest dye yield showed the highest color strength, whereas dye plant Inkoy (leaves) having the highest dye yield showed lower color strength. Each dye plant showed variable color strength in relation to dye yield.

These observations may be explained on the basis of two facts. Firstly, as mentioned earlier no attempt was made to purify the crude dye after evaporation of the aqueous plant extracts and isolate the pure coloring component/s. It may be possible that crude dyes obtained from the present investigation are mixture of various water soluble components, some of which contribute to the color and some do not. The amount of the coloring component present in the crude dye will be the contributing factor for the color strength equivalence (Ceq). Secondly, the color strength equivalence is a measure of the intensity of the color. It is a well known fact that the intensity of the color depends on the nature of chromophore and the auxochromes present in dye molecule. It is obvious that the nature of chromospheres and auxochromes would be varying in different crude solid dyes obtained from different dye plant sources. These two factors will be responsible for the excluding of definite relationship between color strength equivalence and dye yield of plant sources.

In order to get more clarity in understanding and explaining the above observations, purification, and isolation of coloring components from crude dyes and determination of chemical structure of coloring components will be essential. This aspect is beyond the scope of the present investigation.

Color Strength (K/S) on Dyeing

In order to find the suitability of the dye extracts for dyeing, cotton fabric was dyed without mordant and after pre-mordanting. The K/S values of dyed samples were measured using Minota Chroma-Meter CR 210. The wavelength at which, the highest K/S was recorded. The relative increase in K/S after pre-mordanting was expressed in terms of the ratio of K/S values of mordant dyed to un-mordant dyed cotton fabric. The results are shown in Table 4.

For samples dyed by direct method (without mordanting) the K/S values ranged from 0.5-3.0, while for alum and iron (II) sulphate mordant dyed samples, it ranged from 0.8-5.8 and 1.1-8.2 respectively. With mordant dyeing, higher K/S values were observed with few exceptions compared to direct dyed samples. The relative increase in K/S expressed in terms of ratio mordant dyed to direct dyed varied from 0.94 to 9.67 and 0.85 to 6.83 for alum and iron (II) mordanted samples, respectively.

From Table 4 it can be seen that out of 10 chosen dye

plant sources, 8 dye plant sources showed reasonable dyeing without mordanting as seen by the K/S values, indicating that dye extracts from these sources had affinity to cotton. The two dye

plant sources viz, Gimea (flower) and Fesson (flower) showed only tinting, indicating the absence of dye affinity. There was considerable increase in K/S values for samples dyed using mordants.

TABLE 4 K/S VALUES OF DYED COTTON

Local name	Plant parts	K/S value			K/S Ratio	
		K/S Direct dyed	K/S Alum mordant. dyed	K/S Iron(II) mordant dye d	$\frac{\left(\frac{K}{S}\right)_{\text{alum}}}{\left(\frac{K}{S}\right)_{\text{direct}}}$	$\frac{\left(\frac{K}{S}\right)_{\text{iron(II)}}}{\left(\frac{K}{S}\right)_{\text{direct}}}$
Bamiba	Bark	2.7	4.7	3.4	1.74	1.26
Dokima	Bark	2.7	3.4	5.0	1.26	1.85
Warica	Bark	1.7	1.6	4.0	0.94	2.35
Inkoy	Leaves	1.7	1.6	5.5	0.94	3.24
Wonbela	Bark	3.0	5.5	6.7	1.83	2.23
Abalo	Leaves	2.4	6.1	8.2	2.54	3.42
Zana	Leaves	1.3	3.8	1.1	2.92	0.85
Gesho	Leaves	3.0	4.2	5.4	1.40	1.80
Gimea	Flower	0.6	5.8	4.1	9.67	6.83
Fesson	Flower	0.5	0.8	2.4	1.60	4.80

The relative increase in color strength as expressed in terms of ratio of K/S values for mordanted to unmordanted cotton was higher than 1 with the exception of Warika (bark) and Inkoy (leaves) for alum mordanted and Zana (leaves) for iron mordanted samples. The increase in K/S values due to mordanting reveals the presence of suitable groups in dye structure capable to form metal complex which is the typical feature of most of the natural dyes. The absence of increase in K/S ratio beyond 1 in case of some dye plants gives an indication of absence of metal complex formation. The alum mordanted samples showed intensification of color without much change in color hue whereas iron mordanted samples not only showed color intensification, but the hue of color changed to grey-black. This is also a common feature of the two

mordants. Therefore, it can be concluded with some exception that the aqueous extracts of selected dye plants showed capability of dyeing cotton without mordanting. There was deepening of color for mordanted samples.

CIE $L^*a^*b^*$ Determination

The CIE $L^*a^*b^*$ values of samples dyed in presence and absence of mordants were determined, in order to get information about the effect of mordanting in hue change. The measurements were carried out in triplicate at different places of the dyed samples. The results are shown in Table 5. The lightness values (L^*) for mordant dyed samples were decreased for all dye plants compared to sample dyed without mordant, indicating the deepening of shade.

TABLE 5 CIE L*A*B* VALUES OF DYED COTTON

Local name	Plant parts	Direct dyed			Alum mordant dyed			Iron(II) mordant dyed		
		L*	a*	b*	L*	a*	b*	L*	a*	b*
Bamiba	Bark	54.03	6.55	11.41	48.92	7.66	15.94	53.89	3.56	10.12
Dokima	Bark	73.40	7.20	18.73	69.21	7.05	21.43	49.13	2.38	7.09
Warica	Bark	75.40	8.04	19.66	72.96	7.00	22.94	56.16	4.90	17.33
Inkoy	Leaves	78.60	7.69	17.03	75.00	6.17	19.49	45.70	2.36	8.49
Wonbela	Bark	77.04	4.27	21.60	73.14	1.85	30.71	45.50	1.05	7.10
Abalo	Leaves	79.10	3.00	21.30	69.21	7.05	21.43	41.89	0.92	6.23
Zana	Leaves	85.84	3.16	11.67	69.54	1.79	28.19	76.94	2.06	12.52
Gesh	Leaves	70.24	3.23	15.54	63.97	2.93	26.63	54.85	2.38	18.67
Gimea	Flower	82.20	2.30	11.74	70.96	7.75	44.42	54.39	1.69	14.50
Fesson	Flower	85.38	4.66	12.74	78.14	3.47	15.89	50.12	2.36	7.52

The decrease in lightness values was higher for iron (II) mordant samples than that in alum mordant dyed samples both compared to direct dyed samples indicating greater color deepening in case of iron mordant. This is also a common feature of natural dyes with iron mordant, and the shade turns more towards grey-black. The color deepening may be attributed to the metal complex formation with both Alum and iron (II) mordants.

The actual shades obtained with alum mordant were reddish, whereas with iron mordant the shades were grey-black. This is reflected in higher a^* (redness) values for alum mordanted samples, whereas no consistency is observed for variation of b^* (yellowness) values in case of both the mordants.

Wash and Light Fastness

The requirement for textile dyes not only limited by

imparting color to fabric but the color should withstand the action of certain external agencies. The resistance to washing is one of the most important criteria for dye acceptability. The wash fastness of the cotton samples dyed without and with mordants was tested according to ISO 105 C10:2006 (A) method. The results of wash fastness and degree of staining were evaluated using grey scale and shown in Table 6. The results indicated that the staining of adjacent cotton sample was absent as indicated by grade 4-5 for degree of staining, however, there were variations in the wash fastness grade for change in shade. In general, there was improvement in fastness grade for both the mordant dyed samples compared to un-mordanted samples. This observation was expected as the purpose of mordanting is to improve not only color depth but also the wash fastness of dyed sample

TABLE 6 WASH AND LIGHT FASTNESS OF DYED COTTON

Local name	Plant parts	Wash fastness						Light fastness		
		Color change			Staining with bleached cotton					
		Direct dyed	Alum mordant dyed	Iron(II) Mordant dyed	Direct dyed	Alum mordant dyed	Iron(II) Mordant dyed	Direct dyed	Alum mordant dyed	Iron(II) mordant dyed
Bamiba	Bark	2-3	4.0	3.0	4-5	4-5	4-5	2.0	1-2	4.0
Dokima	Bark	4.0	3-4	4-5	4-5	4-5	4.0	2-3	3.0	2.0
Warica	Bark	1-2	2-3	4.0	4-5	4.0	4-5	2.0	2-3	2-3
Inkoy	Leaves	2-3	2.0	4.0	4-5	4.0	4-5	1-2	1-2	2-3
Wonbela	Bark	4.0	3-4	3-4	4-5	5.0	4-5	2-3	2-3	3.0
Abalo	Leaves	4.0	4.0	4.0	4-5	4-5	4-5	3.0	3.0	5.0
Zana	Leaves	3-4	4.0	4-5	4-5	4-5	4-5	3.0	1-2	3.0
Gesho	Leaves	2.0	3.0	3.0	4-5	4-5	4-5	3.0	2-3	3.0
Gimea	Flower	-	3-4	3.0	4-5	5.0	5.0	2-3	1-2	3-4
Fesson	Flower	-	3.0	4.0	4-5	4-5	4-5	3.0	3.0	3-4

All the dyed samples showed the wash fastness within the commercially acceptable limit of grade 3 with only few exceptions like Warika (bark) and Gesho (leaves) for dyeing without mordant. Therefore, the dye plants showing fastness grade of 3 and above can be used as a source of natural dye for dyeing of cotton on commercial scale (Kothari, 1999).

The light fastness results are also shown in Table 6. The improvement in light fastness with alum mordant dyeing was insignificant compared to samples dyed without mordant. Light fastness with iron (II) mordant dyeing showed improvement for some dye plants (Bamiba, Abalo, Gimea and Fesson dye plants) as shown in Table 6. In general, the selected dye plants showed unsatisfactory light fastness with only few exceptions. This is a common feature of natural dyes as reported in literature (Ashis Kumar and Priti, 2009).

Conclusion

The percentage crude dye yield resulted from evaporation of dye plant extracts, color strength equivalence (Ceq) and color mass equivalence (Meq) compared to commercial C I Reactive Red 4, indicated that dye plants under this study have considerable potential for application as a source of natural dye for cotton dyeing. The color strength (K/S) both for unmordant and mordant dyed cotton fabric samples, wash fastness test results also indicated that most dye plants under this investigation have affinity and showed acceptable wash fastness. However, there is scope for improvement of light fastness.

There was deepening of shades after mordanting clearly indicated by the changes in L^* values. The deepening was more in case of iron mordant compared to alum. The shades obtained with alum mordant were reddish reflected in higher a^* values, whereas no consistency was observed for changes in b^* (yellowness) values for both the mordants.

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